First Detection of O2 Recombination Nightglow Emission at 1.27 μm in the Atmosphere of Mars With OMEGA/MEX and Comparison with Model

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FIRST DETECTION OF O_2 RECOMBINATION NIGHTGLOW EMISSION AT 1.27 µm IN THE ATMOSPHERE OF MARS WITH OMEGA/MEX AND COMPARISON WITH MODEL

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Introduction:

In the upper atmospheres of both Venus and Mars, CO_2 and N_2 molecules are photo-dissociated with a production of O and N atoms in the thermosphere (z> 90 km) on the dayside. The thermospheric circulation of Venus is characterized by a strong flow from the sub solar point to the antisolar point (so called SSAS); in the descending air parcel on the night side, atoms of O and N are recombining, and produce both UV NO emission nightglow [1] and near IR O_2 at 1.27 µm [2]. While the NO emission was already detected in the atmosphere of Mars [3], the O_2 recombination emission had escaped detection up to now. Here we report the first detection of this night side O_2 emission in the atmosphere of Mars, from observations of the OMEGA imaging spectrometer on board Mars Express. Such observations, which trace uniquely a downward advection transport mechanism, are compared with the prediction of the LMD GCM with photochemistry. The main features of the observations are indeed predicted by the model in which air transport is simulated by advection, with no need of eddy diffusion.

The recombination of O atoms requires a third body (mainly CO_2):

$$O+O+CO_2 \rightarrow O_2\,[^1\Delta] + CO_2 \qquad (1)$$

The O_2 molecule is produced in an excited state $[^1\Delta]$ which de-excites spontaneously with a time constant of about 1.24 hr: O_2 $(a^1\Delta_g \rightarrow X_3\Sigma_g)$, or may be quenched by collisions.

Let us consider an air parcel which has been exposed to daylight and photo-dissociation by solar UV (z> 70 km). For a given mixing ratio $\mu=[O]/[CO_2]$, the reaction rate of recombination (1) (per cm^3.sec) is proportional to $[O]\,[O]\,[CO_2] = \mu^2\,[CO_2]^3$, the cube of CO_2 density. While an air parcel is descending, $[CO_2]$ increases and O atoms are recombining more and more, until exhaustion of O atoms.

There is another mechanism which produces the same 1.27 µm emission: photo-dissociation of ozone on the day side, which was detected from ground based observations ([4], Noxon et al., 1976), and monitored from orbiters like Mars Express as a useful mean to quantify ozone ([5],[6]) or from ground based telescopes ([7], Kranospolsky, 2003). We will argue in the following that the observations of OMEGA, performed on the winter polar night, are not due to ozone photo-dissociation but rather to oxygen recombination.

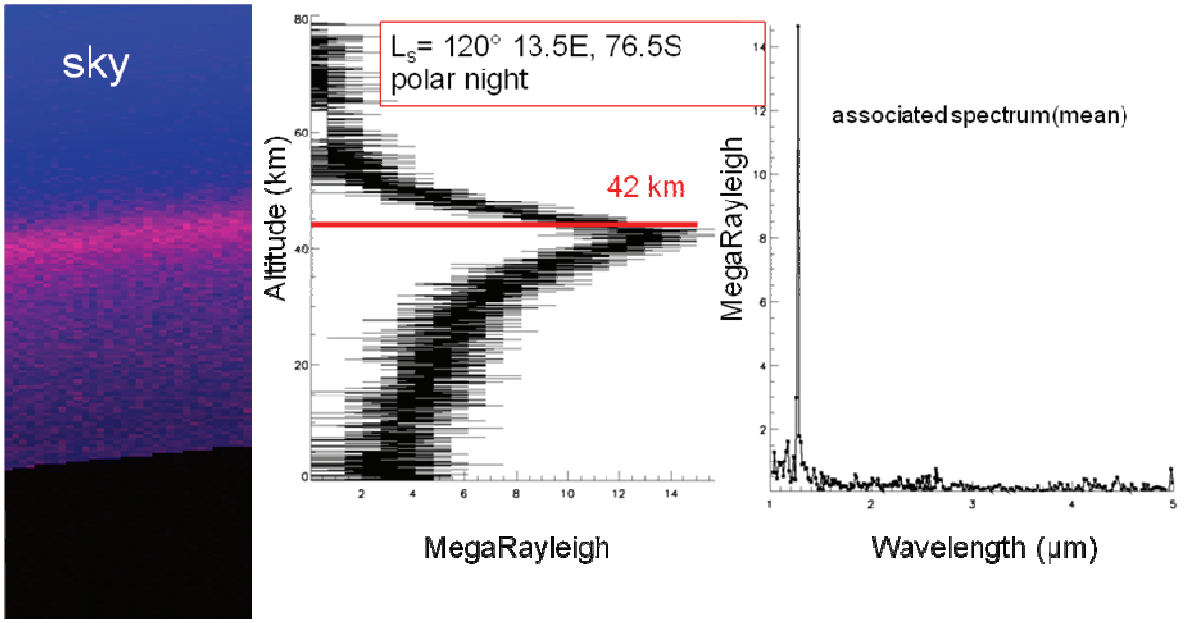

Figure 1. Left: A swath of the observed limb at night by OMEGA, with emission coded in pink. Middle: vertic-

al distribution of the intensity observed in megaRayleigh (integration over azimuth). Right: integrated observed spectrum, showing emission only at 1.27 µm.

2. Observation with OMEGA on Mars Express.

OMEGA is a VIS/NIR hyperspectral imager operating on board of the ESA/Mars Express mission. The instrument is made of two co-aligned channels: a pushbroom "VIS" channel acquires up to 128 spectra (from 0.35 to 1 µm) simultaneously on a CCD matrix; a NIR channel (1 to 5.1 µm) operates in whiskbroom mode (scanning mirror across track), with two linear InSb detectors (128 pixels each), and 13 nm spectral sampling in the range 1 to 2.5 µm. Nadir and limb pointing can be implemented. OMEGA identifies and maps both surface (minerals, ices, frosts) and atmospheric (gas, aerosols, clouds) species, with in particular CO_2, CO, H_2O and O_3 gaseous detections. The 1.2 mrad IFOV corresponds to a footprint from 0.3 to 4 km (depending on S/C altitude or distance to the limb.)

Up to 2010, OMEGA has observed 40 times the atmosphere above the limb at night. In three cases out of 40, an intense emission at 1.27 µm was detected, with a peak emission of 12 megarayleigh at an altitude above the areoid of 42 km (Figure 1) in the whole FOV scanned during the observation. The rest of the spectrum remains void of any detectable emission. At the latitude (76.5° S) and season (Ls=120°) of fig.1 observation, the observed air parcel is never illuminated over a diurnal cycle, and therefore, the emission cannot be a remnant of the ozone photo-dissociation process.

3. Comparison with model.

The version of the LMD GCM with coupled photochemistry developed by Lefèvre et al. (2004) [8] was run with the implementation of the calculation of O_2 emission from recombination reaction (1) over a full martian year. The emission rate was integrated vertically, zonally averaged, and plotted as a function of season and latitude on figure 2 in units of megarayleigh (10^{12} photons/cm2 s). The emission is present only at high latitudes, is absent during summer, and not perfectly symmetrical between North and South. Places where OMEGA detected the emission are represented by stars. They are located in the regions/seasons where emission should occur, as predicted by the model.

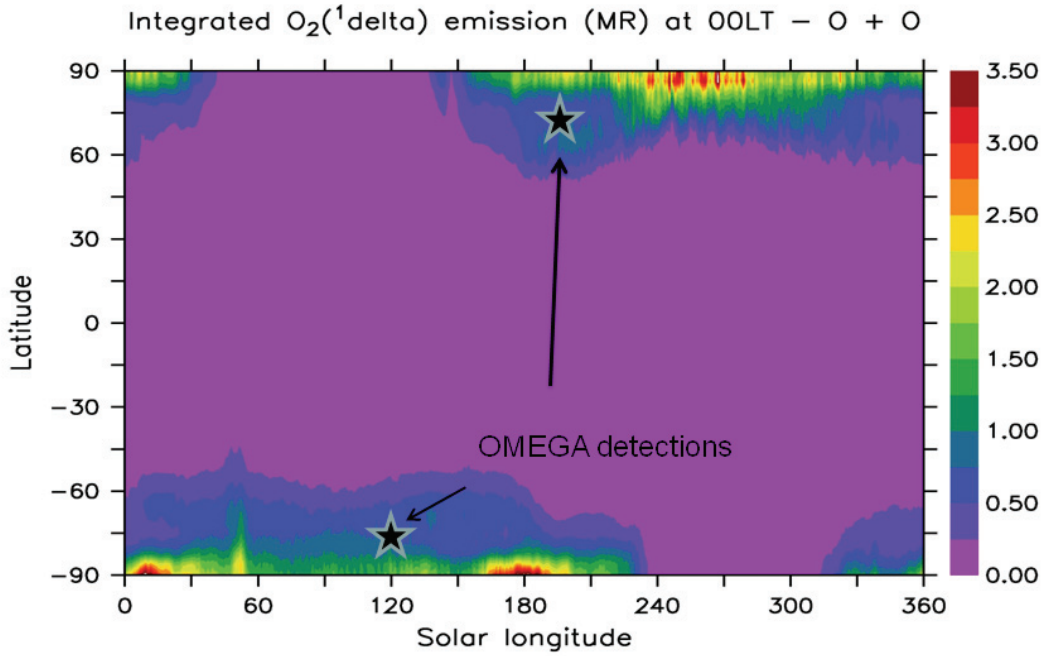

Figure 2. Latitude/season maps of zonally averaged vertical emission rate of O+O recombination in units of megaRayleigh. Locations where OMEGA detected an emission (stars) are in the regions predicted by the model. The vertical intensity of OMEGA is computed to be 0.24 Megarayleigh for the South polar observation, smaller than model prediction

On figure 3 are compared the vertical distribution of the 1.27 µm emission observed at the limb by OMEGA and a model distribution. The overall shape is in good agreement, with only a slight difference in the peak altitude (42 km observed versus 45 km in the model). The main differences are: observations are less intense (ratio data/model =0.25 to 0.35, up to 40 km), with a strong deficit in the observations above 45 km, possibly indicative of a slab of air of different origin than the rest of the atmosphere. For this particular condition of observation, the model shows that no emission at 1.27 µm is expected from O_3 photo-dissociation (not shown here).

On figure 4 is represented the distribution of O

atoms relevant to the season Ls= 115-120° (zonal average). Superimposed is the meridional stream-function, describing the atmospheric general circulation in latitude-altitude. Atomic oxygen is present mainly above 80 km where it is produced by the photolysis of CO_2, and in the descending branch of the high atmosphere Hadley cell ascending from the north pole. Air is diving down in the south polar vortex where recombination of O atoms may be observed.

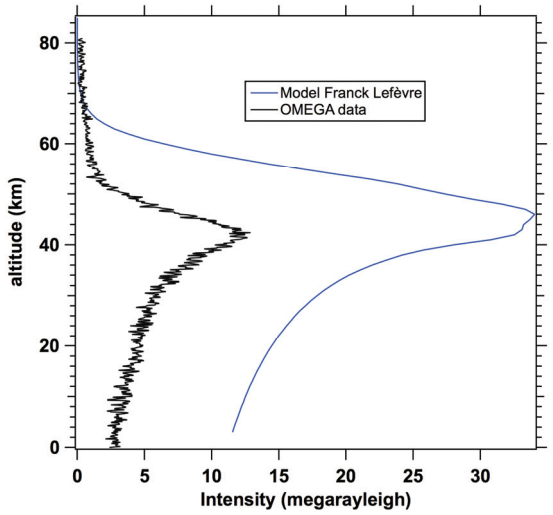

Figure 3. Comparison of OMEGA O_2 intensity (1.27 µm) at the limb with the LMD GCM prediction for Ls=120°, latitude= 76.5° S.

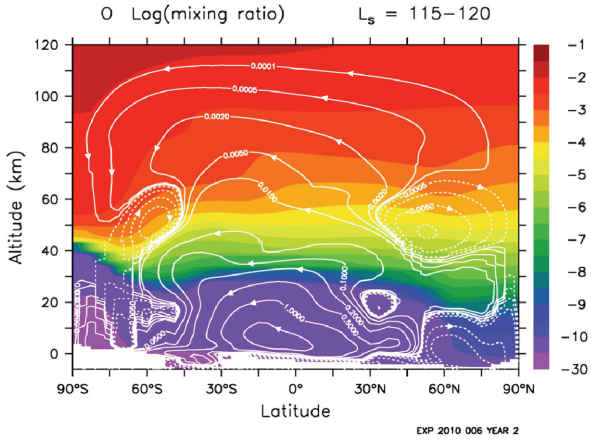

Figure 4. The atomic oxygen mixing ratio calculated by the LMD GCM for the season Ls= 115-120° (zonal average). Superimposed is the meridional stream function (10^9 kg.s^{-1}),showing strong descending motion over the South pole.

4. Conclusion.

Comparison of observations to model show great similarities, but also some significant differences (smaller intensity, absence of emission above 50 km. This may be due to day-to-day meteorological variability of the upper atmosphere of Mars, or to some fine-tuning needed in the model [8]. In any case, the O+O emission at 1.27 µm is tracing the descent of air originating in the altitude region of CO_2 photodissociation (say, >70 km). Therefore, Figure 2 is a mapping of the mesospheric air descent latitude/season pattern. Since the lifetime of methane is only one week instead of 200 years at low altitude, the actual lifetime of one methane molecule will depend on the rate at which the whole atmosphere is recycled through the circulation at high altitude. Observations of O+O emission offers the possibility to constrain the GCM models, which in turn may be used to estimate the recycling rate through the high altitude region in the upper atmosphere of Mars. It may help to alleviate the theoretical problems associated to reported variations of methane.

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